A surprisingly large disk galaxy in the early Universe

A galaxy has been discovered at an early cosmic time – two billion years after the Big Bang – that has a giant disk, grown to a size more typical of the largest disks in the present Universe. The early and quick growth of this disk might be related to its special, over-dense environment.

The question

When and how galaxy disks form is an outstanding puzzle in modern astronomy. The first few years of observations from the James Webb Space Telescope (JWST) have revealed a plethora of galaxy disks in the early Universe, at redshift $z > 3$, which corresponds to a cosmic epoch of eleven billion years ago, or two billion years after the Big Bang. These observations have raised some tension with previous studies which reported that disks often form later, at $z \sim 2$ or below[1,2].

How quickly did these new-found disks form and grow in the early cosmic epochs? Is their formation in any way connected to the cosmic environment they exist in? Answers to these questions are essential pieces in the puzzle of disk formation: to find them, we turned our focus to the early Universe and a special cosmic environment.

The discovery

We conducted our study using new observations from JWST, complemented by data from other facilities such as the Hubble Space Telescope, the Very Large Telescope (VLT) and the Atacama Large Millimeter/submillimeter Array (ALMA). These observations were targeted towards a specific region of the sky, which hosts a bright quasar at redshift $z = 3.25$. Previous studies have revealed that the quasar is embedded in a large-scale structure called a proto-galaxy cluster, which has a high concentration of galaxies, gas and black holes – an exceptionally over-dense environment[3–5]. Using data from two instruments, the Near-Infrared Camera and Near-Infrared Spectrograph, onboard JWST, we identified galaxies within this over-dense region and analysed their redshifts, morphology and kinematics, all of which are needed for the identification of galaxy disks.

The observations led us to the serendipitous discovery of a surprisingly large disk in the large-scale structure. This galaxy, dubbed the 'Big Wheel' (Fig. 1), has an optical radius of around 10 kpc, which is about three times as large as the typical galaxies previously discovered at similar stellar masses and cosmic time, and also at least three times as large as what is predicted by current cosmological simulations. The giant disk features multiple blue clumps and spiral arms – these consist of massive young stars, formed inside the galaxy, which are not obscured by dust.

Further kinematics analysis, based on the data from the Near-Infrared Spectrograph, confirmed that the galaxy is a disk rotating at around 300 km s^{-1}. It is larger than any of the kinematically confirmed disks found at similar early epochs, but is comparable to the sizes of most massive disks seen in the present Universe.

The implications

Our findings indicate the quick growth of a massive galaxy disk in an early cosmic epoch. Interestingly, the disk exists in a highly over-dense environment, hinting that such an environment might offer favourable physical conditions for early disk formation.

Given that there is a lack of galaxies comparable to the Big Wheel emerging from cosmological simulations, it seems likely that these favourable physical conditions are not fully captured in current galaxy-formation models. Specifically, an environment of this kind is known to host frequent galaxy encounters and mergers, and gas flows. Therefore, for a disk to form early and grow quickly, galaxy mergers in this environment must have been non-destructive and oriented in particular directions. Alternatively, gas inflows could have carried angular momentum that largely corotated with the galaxy disk: these inflows would become smoothly integrated into the disk from its outskirts, without disturbing the ongoing disk rotation, and the disk would grow quickly in size.

Over-dense environments such as the one hosting the Big Wheel remain relatively under-explored territory. More, targeted observations from facilities including JWST, the VLT and ALMA are needed to build a statistical sample of giant disks in the early Universe and open up a window on the early phases of galaxy formation.

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EXPERT OPINION

"This paper presents compelling evidence for a spiral galaxy at $z > 3$ that is much larger and more massive than any previously known, rotationally supported disk at this epoch. The existence of such massive spirals at this epoch — and the fact that this one lies in a particularly dense environment — is an interesting extension of what was previously known, and highlights the need for galaxy-formation models to better probe high-density environments." **An anonymous reviewer.**

FIGURE

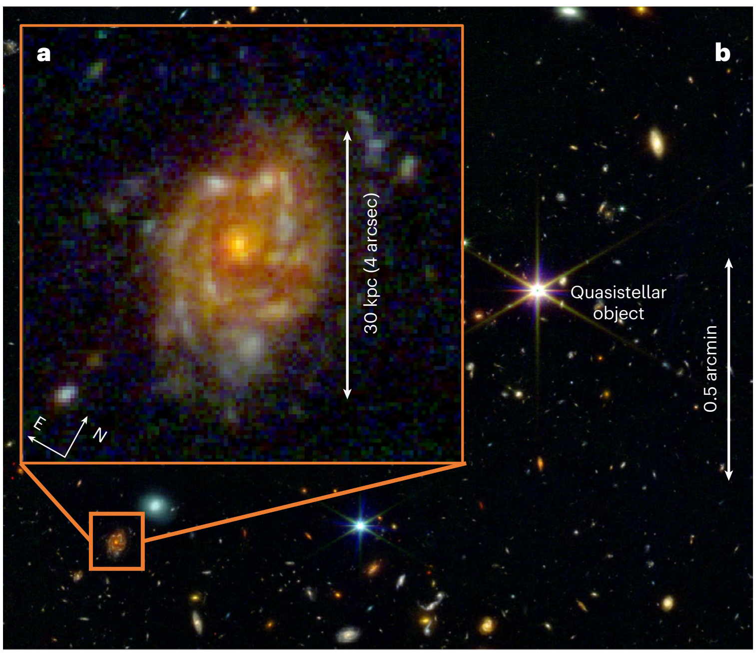

Fig. 1 | The Big Wheel galaxy and its cosmic environment. **a**, The galaxy is a giant rotating disk at redshift $z = 3.25$, with clear spiral arms. It is so far unique for its large disk size of around 10 kpc – larger than any other galaxy disks confirmed at similar redshifts. **b**, The galaxy formed and evolved in this highly over-dense cosmic environment, around a bright quasistellar object, or quasar. © 2025, Wang, W. et al., CC BY-NC-ND 4.0.

BEHIND THE PAPER

The discovery of this galaxy was in no way expected. Our JWST observation programme was originally intended for the study of diffuse gas emission around a distant quasar, at $z = 3$. However, on receiving the first batch of imaging data in late 2022, we noticed a galaxy with a spectacular disk and spiral-arm features. It appeared so large on the image that we thought that it was most likely to be a nearby galaxy, at low redshift. But data from ground-based telescopes indicated another possibility: that its redshift could be near that of the quasar, the galaxy could be from an early cosmic epoch.

To resolve the ambiguity, we conducted follow-up spectroscopic observations to pinpoint the redshift. These confirmed that the galaxy is indeed near the quasar redshift and in a proto-galaxy cluster associated with the quasar. The data also revealed the beautiful disk-like rotation pattern of the galaxy. **W.W. & S.C.**

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FROM THE EDITOR

"The combination of a unique observational discovery — facilitated by JWST — with thoughtful analysis allows this study to offer new insight into the chain of influence of the environment on galaxy evolution at early times. The mystery that remains, however, is what such an unusual system might evolve into in the present day." **Lindsay Oldham, Associate Editor, *Nature Astronomy*.**